Speech by Alexander Graham Bell, March 4, 1907

PROCEEDINGS OF THE WASHINGTON ACADEMY OF SCIENCES

VOL. VIII, pp. 407–448. PLATES IX–XX MARCH 4, 1907

W. Orville Wright with Kind regards from Alexander Graham Bell

AERIAL LOCOMOTION

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WASHINGTON, D. C. PUBLISHED BY THE ACADEMY

1907

407

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Vol. VIII, PP. 407–448. PLS. IX–XX March 4, 1907.

AERIAL LOCOMOTION. With a Few Notes of Progress in the Construction of an Aerodrome. 1 By Alexander Graham Bell.

1 An address presented before the Washington Academy of Sciences, December 13, 1906.

Proc. Wash. Acad. Sci., March, 1907.

The history of aerial locomotion is full of tragedies; and this is specially true where flying machines are concerned. Men have gone up in balloons and most of them have come down safely. Men have launched themselves into the air on wings, and most have met with disaster to life or limb. There have been centuries of effort to produce a machine that should fly like a bird, and carry a man whithersoever he willed through the air; and previously to 1783, the year sacred to the memory of the brothers Montgolfier, all experiments at aerial locomotion had this end exclusively in view.

Then came a period when the conquest of the air was sought through the agency of balloons. For more than one hundred years the efforts of experimenters were chiefly directed to the problem of rendering the balloon dirigible; and the earlier experiments with gliding machines, and artificial wings — and the projects of men to drive heavy bodies through the air by means of propellers, were largerly forgotten. The balloon was changed from its original spherical form to a shape better adapted for propulsion; and at last through the efforts of Santos Dumont we have arrived at the dirigible balloon of to-day. But in spite of the dirigibility of the modern balloon, it has so 408 far been found impracticable to impart to this frail structure a velocity sufficient to enable it to make headway against anything but the mildest sort of wind. The character of the balloon problem has therefore changed. Velocity of propulsion rather than dirigibility is now the chief object of research.1

1 Some of the latest forms of dirigible balloons are shown in Plates XIX and XX.

It has long been recognized by a growing school of thinkers, that an aerial vehicle, in order to cope with the wind, should be specially heavier than the air through which it moves. This position is supported by the fact that all of Nature's flying models, from the smallest insect to the largest bird, are specifically heavier than the air in which they fly, most of them many hundreds of times heavier, and that none of them adopts the balloon principle in flight. It is also significant in this connection that some of Santos Dumont's most celebrated exploits were accomplished with quite a small balloon so ballasted as to sink in the air instead of rise. He was then enabled, under the influence of his motive power, to steer his balloon upwards without the expenditure of ballast, and to descend without the loss of gas. This probably typifies — for the balloon — the direction of change in the future. a reduction in the volume of gas, coincidently with an increase in motive power, will lead to greater velocity of propulsion — now the main desideratum. Then, dependence upon velocity for support rather than gas, may gradually lead to the elimination of the gas-bag altogether: in which case the balloon will give birth to a flying machine of the heavier-than-air type.

However this may be it is certainly the case that the tendency of aerial research is to-day reverting more and more to the old lines of investigation that were pursued for hundreds of years before the invention of the balloon diverted attention from the subject. The old devices have been reinvented. The old experiments have been tried once more. Again the birds are recognized as the true models of flight; and again men have put on wings — but this time with more promise of success.

Lilienthal boldly launched himself into the air in an apparatus of his own construction having wings like a bird and a tail for a rudder. Without any motor he ran down hill against the wind. 409 Then, upon jumping into the air, he found himself supported by his apparatus, and glided down hill at an elevation of a few feet from the ground,landing safely at a considerable distance from his point of departure. This exhibition of gliding flight fairly startled the world, and henceforth the experiments of Lilienthal were conducted in the public eye. He made hundreds of successful flights with his gliding machine, varying its construction from time to time, and communicating to the world the results of his experiments with practical directions how to manage the machine under circumstances of difficulty. So that, when at last he met with the usual fate of his predecessors in this line, the experiments were not abandoned. They were continued in America by Chanute of Chicago, Herring, and other Americans, including the Wright brothers of Dayton, Ohio. (See Plate IX.)

Hargrave, of Australia, attacked the flying machine problem from the standpoint of a kite, communicating his results to the Royal Society of New South Wales. It is to him we owe the modern form of kite known as the “Hargrave Box Kite,” which surpasses in stability all previous forms of kites. He also constructed successful flying machine models on a small scale using a store of compressed air his motive power. He did not attempt to construct a large sized apparatus, or to go up into the air himself — so he still lives, to carry on researches that are of interest and value to the world.

No one has contributed more to the modern revival of interest in flying machines of the heavier-than-air type than our own Professor Langley, the late Secretary of the Smithsonian Institution. The constant failures and disasters of the past had brought into disrepute the whole subject of aerial flight by man; and the would-be inventor, or experimenter, had to face — not only the natural difficulties of his subject, but the ridicule of a sceptical world. To Professor Langley is due the chief credit of placing this subject upon a scientific basis, and of practically originating what he termed the art of “Aerodromics.” In his epoch-making work on “Experiments in Aerodynamics,” published in 1891 among the Smithsonian Contributions to Knowledge, he prepared the world for the recent advances in this art 410 by announcing that: “The mechanical sustention of heavy bodies in the air, combined with very great speeds, is not only possible, but within reach of mechanical means we actually possess.”

He also attempted to reduce his principles to practice, by the construction of a large model of an aerodrome driven through the air by a steam engine under the action of its own propellers. I was myself a witness of the memorable experiments made by Professor Langley on the 6th of May, 1896, with this large sized model, which had a spread of wing of about 14 feet. No one who witnessed the extraordinary spectacle of a steam engine flying with wings in the air, like a great soaring bird, could doubt for one moment the practicability of mechanical flight. I was fortunate in securing a photograph of this machine in full flight in the air, so that an automatic record of the achievement exists. (See Plate X). The experiment realized the utmost hopes and wishes of Professor Langley at that time: “I have brought to a close,” he says, “the portion of the work which seemed to be specially mine — the demonstration of the practicability of mechanical flight; and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others. The world, indeed, will be supine if it does not realize that a new possibility has come to it, and that the great universal highway over-head is now soon to be opened."

But the world was not satisfied with this position. It looked to Professor Langley himself to carry on the experiments to the point of actually transporting a human being through the air on an aerodrome like his model; and so, with the aid of an appropriation from the War Department of the United States, Professor Langley actually constructed a full sized aerodrome, and found a man brave enough to risk his life in the apparatus — Mr. Manly, of Washington, D. C.

Great public interest was aroused; but Professor Langley did not feel justified in giving information to the public, and therefore to foreign nations, concerning experiments undertaken in the interests of the War Department. His own dislike to premature publicity coöperated with his conscientious scruples, to 411 lead him to deny the newspapers the opportunity of witnessing the experiments. But the newspapers insisted upon being represented. The correspondents flocked to the scene, and camped there for weeks at considerable expense to their papers. They watched the house-boat containing the aerodrome by day and by night; and, upon the least indication of activity within, newspaper reporters were on hand in boats. After long delay in hopes of securing privacy it was at last decided to try the apparatus; but newspaper representatives, embittered by the attempts to exclude them, were bringing the experiments into public contempt. They nicknamed the apparatus "The Buzzard," and were all ready to presage defeat.

Two experiments were made; but on both occasions the apparatus caught in the launching ways, and was precipitated into the water without having a chance to show what it could do in the air. The newspapers immediately announced to the world the failure of Professor Langley's machine, and ridiculed his efforts. The fact of the matter is, that the machine was never tried; and that there was no more reason for declaring it a failure than for deciding that a ship would not float that has never been launched. After having witnessed the successful flight of the large sized model of 1896, I have no doubt that Professor Langley's full sized aerodrome would have flown had it been safely launched into the air. (See Plate XI.)

When the machine was for the second time precipitated into the water it was not much damaged by the accident. Professor Langley, of course, was more anxious about the fate of his intrepid assistant than of his machine, and followed Mr. Manly into the house-boat to ascertain his condition. During this temporary withdrawal from the scene of the catastrophe, the crew of a tug-boat grappled the frail framework of the submerged aerodrome; and in the absence of any one competent to direct their efforts, they broke the machine to pieces, thus ending the possibility of further experiments without the expenditure of much capital. The ridicule of the newspapers however effectually prevented Professor Langley from securing further financial aid; and, indeed, broke his heart. There can be little doubt that the unjust treatment to which he 412 was exposed contributed materially to the production of the illness that caused his death.

He lived long enough however to know of the complete fruition of his hopes by others; and, only two days before his death, he had the gratification of receiving a communication from the newly formed Aero Club of America, recognizing and appreciating his efforts to promote mechanical flight. This communication read as follows:

RESOLUTIONS OF THE AERO CLUB OF AMERICA, ADOPTED JANUARY 20, 1906.

“ Whereas, Our esteemed colleague, Dr. S. P. Langley, Secretary of the Smithsonian Institution, met with an accident in launching his aerodrome, thereby missing a decisive test of the capabilities of this man-carrying machine, built after his models which flew successfully many times; and

“ Whereas, In that difficult experiment, he was entitled to fair judgment and distinguished consideration because of his important achievements in investigating the laws of dynamic flight, and in the construction of a variety of successful flying models: Therefore be it

“ *Resolved,* That the Aero Club of America, holding in high estimation the contributions of Dr. Langley to the science of Aerial Locomotion, hereby expresses to him its sincerest appreciation of his labors as a pioneer in this important and complex science; and

“ *Be it further resolved,* That a copy of these resolutions be sent to the Board of Regents of the Smithsonian Institution, and to Dr. Langley.”

Professor Langley was on his death bed when these resolutions were brought to his attention, and when asked what should be done with the communication his pathetic answer was “Publish it.” To all who knew his extreme aversion to publicity in any form this reply indicates how keenly he felt the misrepresentation of the press.

Both in the case of Lilienthal and Langley their efforts have not been in vain. Others have continued their researches; and today the world is in possession of the first practical flying-machine — the 413 creation of the brothers Orville and Wilbur Wright, of Dayton, Ohio. Indeed we have news from France that a second has just appeared constructed by the same Santos Dumont to whom the world already owes the first practical dirigible balloon.

The Wright brothers began by repeating the gliding experiments of Lilienthal with improved apparatus of the Hargrave type as modified by Chanute. (See Plate XII.) After having made many successful glides through the air without a motor, they followed in the footsteps of Langley and propelled their machine by means of twin screws operated by engine power. They successful in launching their apparatus into the air, and it flew, carrying one of them with it. Their machine has flown not once simply, but many times, and in the presence of witnesses; so that there can be no doubt that the first successful flying-machine has at last appeared. Specially successful flights were made on the third and fourth of October 1905, which were referred to by the Wright brothers in a letter to the Editor of *L'Aerophile* published in that journal, January, 1906. They have also made a communication upon the subject to the Aero Club of America; and have received the formal congratulations of that organization upon their success.

Each of the Wright brothers, in turn, has made numerous flights over their testing field near Dayton, Ohio, sometimes at an elevation of about 80 feet, at another times skimming over the field at a height of about ten feet from the ground. They have been able to circle over the field of operation, and even to describe in the air the figure eight, thus demonstrating their perfect control over their apparatus both in the vertical and horizontal directions. They have succeeded in remaining continuously in the air for more than half an hour — thirty-eight minutes in fact — and only came down on account of the exhaustion of their fuel supply. They state that the velocity attained was one kilometer per minute, or about 37 miles an hour. The machine has not only sustained its own weight in the air during these trials, but has also carried a man, and a gasoline engine weighing 240 lbs., exerting a force of from 12 to 15 horse power, and in addition an extra load of 50 lbs. of pig-iron. The 414 apparatus complete with motor weighed no less than 925 lbs. while the supporting surfaces consisted of two superposed aeroplanes each measuring six by 40 feet; so that the machine as a whole had a flying-weight of nearly two lbs. per square foot (1.0 lbs.).

Thanks to the efforts of the Wright brothers the practicability of aerial flight by man is no longer problematical. We can no longer consider as impossible that which has already been accomplished. America may well feel proud of the fact that the problem has been first solved by citizens of the United States.

A FEW NOTES OF PROGRESS IN THE CONSTRUCTION OF AN AERODROME.

For many years past, in fact from my boyhood, the subject of aerial flight has had a great fascination for me. Before the year 1896 I had made many thousands of still unpublished experiments having a bearing upon the subject; and I was therefore much interested in the researches of Professor Langley relating to aerodynamics. We were thrown closely together in Washington and although we rarely conversed upon aerodynamics we knew that we had a subject of mutual interest and showed the greatest personal confidence in one another. I did not hesitate to show him my experiments, he did not hesitate to show me his. At least as early as 1894, Professor Langley visited me in my Nova Scotia home and witnessed some of my experiments; and in May, 1896, he reciprocated by inviting me to accompany him to Quantico, Virginia, and witness a trial of his large sized model. The sight of Langley's steam aerodrome circling in the sky convinced me that the age of the flying machine was at hand. Encouraged and stimulated by this remarkable exhibition of success, I quietly continued my experiment in my Nova Scotia laboratory in the hope that I too might be able to contribute something of value to the world's knowledge of this important subject.

Warned by the experience of others, I have sought for a safe method of approach — a method that should risk human life as little as possible during the earlier stages of experiment. Experiments with aerodromes must necessarily be fraught with 415 danger, until man, by practical experience of the conditions to be met with in the air, and of the means of overcoming them, shall have attained skill in the control of aerial apparatus. A man cannot even ride a bicycle without practice; and the birds themselves have to learn to fly. Man, not having any inherited instincts to help him in this matter, must first control his flight consciously, guided by knowledge gained through experiment. Skill can only be obtained by actual experience in the air; and this experience will involve accidents and disasters of various sorts before skill can be obtained. If these disasters should, as so often in the past, prove fatal to the experimenter, the knowledge obtained by the would-be aviator will be lost to the world, and others must begin all over again, instead of pursuing the subject where he left off, with the benefit of his knowledge and his experience. It is therefore of the utmost consequence to progress in the art of aviation, that the first attempts to gain experience in the air should be made under such conditions of safety as to reduce to a minimum the liability to fatal results.

The wright brothers' successful flying machine travels at the rate of about thirty-seven miles an hour; and, judging from its great flying weight (nearly two pounds per square foot of supporting surface), it is unlikely that it could be maintained in the air if it had very much less velocity. But should an accident happen to a body propelled through the air with the velocity of a railroad train, how about the safety of the occupants? Accidents will happen, sooner or later, and the chances are largely in favor of the first accident being the last experiment. While therefore we may look forward with confidence to the ultimate possession of flying machines exceeding in speed the fastest railroad trains, it might be the part of wisdom to begin our first experiments at gaining experience in the air, with machines travelling at such moderate velocities as to reduce the chances of a fatal catastrophe to a minimum. This means that they should be light-flying machines; that is, the ratio of weight to supporting surface should be small.

While theory indicates that the greater the weight in proportion to supporting surface consistent with flight, the more independent of the wind will the machine be, yet it might be advisable 416 to begin, if possible, with such a moderate flying-weight as to permit of the machine being flown as a kite. There would be little difficulty then in raising it into the air; and, should an accident happen to the propelling machinery, the apparatus would descend gently to the ground; or the aviator could cast anchor, and his machine would continue flying — as a kite — if the wind should prove sufficient for its support. If it could fly, as a kite, in a ten-mile breeze, then a velocity of only ten miles an hour would be sufficient for its support as a flying maching in calm air, while a less speed would suffice in heading into a moderate wind.

Such velocities would be consistent with safety in experiments, especially if the flights should be made over water instead of land, and at moderate elevations above the surface. Under such circumstances the inevitable accidents which are sure to happen during first experiments are hardly likely to be followed by more serious consequences than a ducking to the man, and the immersion of the machine. If the man is able to swim, and the machine to float upon water, little damage need be anticipated to either.

There are two critical points in every aerial flight — its beginning and its end. A flying machine adapted to float upon water not only seems to afford a safe means of landing, but also promises a solution of that most difficult of problems — a safe method of launching the apparatus into the air. If the supporting floats are so formed as to permit of the machine being propelled over the surface of the water like a motor boat, then, if sufficient headway can be gained under the action of her aerial propellers, the machine can be steered upwards into the air, rising from the water, after the manner of a water bird, in the face of the wind. This seems to be the safest method of gaining access to the air; but, of course, its practicability depends upon possibilities of lightness and speed yet to be demonstrated.

In any event, if the machine, man and all, is light enough to be flown as a kite, it can be towed out of the water into the air through the agency of a motor boat; and, upon land, it would not even be necessary for it to gain headway before rising, for, 417 in a supporting wind, it would rise of itself into the air, if relieved of the weight of the man, and fly as a kite. It would then be a comparatively simple matter to lower the kite to a convenient height from the ground, and to hold it steadily in position by subsidiary lines, while the aviator ascends a rope ladder to his seat in the machine. In this way the man would not be exposed to danger during the critical operation of launching the apparatus into the air; and, by a converse process, a safe landing could be effected without bringing the machine to the ground. The chance of injury to the machine itself would also be much lessened by relieving it of the weight of the man during the initial process of launching, and the final process of bringing the machine down to the ground.

Such speculations as these of course are only justifiable upon the assumption that it is possible to construct an aerial vehicle large enough and strong enough to support a man and an engine in the air, and yet light enough to be flown as a kite in a moderate breeze with the man and engine and all on board. My experiments in Nova Scotia have demonstrated that this can be done; and I now therefore find myself seriously engaged in the attempt to reduce these ideas to practice by the actual construction of an aerodrome of the kite variety. The progress of experiment may be divided into three well marked stages — the kite stage, the motor boat stage, and the free flying-machine rising from the water.

THE KITE STAGE.

In April, 1899, I made my first communication on the subject of kites to the National Academy of Sciences in a paper entitled, “Kites with Radial Wings,” which was reviewed, with illustrations, in the Monthly Weather Review for April, 1899 (Vol. XXVI, pp. 154–155, Plate XI). I made another communication to the National Academy on the 23rd of April, 1903, upon “The Tetrahedral Principle in Kite Structure,” which was published, with 91 illustrations and an appendix, in the National Geographic Magazine for June, 1903 (Vol. XIV, pp. 220–251). The substance of the present address was presented, in part, to the National Academy of Sciences at their recent 418 meeting in Boston, Mass., November 21, 1906. The experiments referred to, which were undertaken at first for my own pleasure and amusement, have gradually assumed a serious character from their bearing upon the flying-machine problem.

The word “kite” unfortunately is suggestive to most minds of a toy — just as the telephone at first was thought to be a toy — so that the word does not at all adequately express the nature of the enormous flying structures employed in some of my experiments. (See Plates XVI, XVII, XVIII.) These structures were really aerial vehicles rather than kites, for they were capable of lifting men and heavy weights into the air. They were flown after the manner of kites, but their flying cords were stout manilla ropes. They could not be held by hand in a heavy breeze; but had to be anchored to the ground by several turns of the ropes around stout cleats like those employed on steamships and men-of-war.

One of the great difficulties in making a large structure light enough to be flown as a kite, has been pointed out by Professor Simon Newcomb in an article in McClure's Magazine published in September, 1901, entitled “Is the Air-Ship Coming?”; and this difficulty had so much weight with him at that time as to lead him to the general conclusion that — “The construction of an aerial vehicle which could carry even a single man from place to place at pleasure, requires the discovery of some new metal, or some new force.”

This conclusion the Wright brothers, and now Santos Dumont, have demonstrated to be incorrect; but Professor Newcomb's objections undoubtedly have great force, and reveal the cause of failures of attempts to construct large-sized flying-machines upon the basis of smaller models that actually flew. Professor Newcomb shows that where two aerial vehicles are made exactly alike, only differing in the scale of their dimensions, the ratio of weight to supporting surface is greater in the larger one than in the smaller; the weight increasing as the cube of the dimensions, whereas the supporting surfaces only increase as the squares. From this the conclusion is obvious that if we make our structure large enough it will be too heavy to fly even by itself — far less be the means of supporting an additional load 419 like a man, and an engine for motive power. This conclusion is undoubtedly correct in the case of structures that are “exactly alike, excepting in their dimensions,” but it is not true as a general proposition.

A small bird could not sustain a heavy load in the air; and while it is true that a similar bird of double the dimensions would be able to carry a less proportionate weight because it is itself heavier in proportion to its wing surface than the smaller bird — eight times as heavy in fact, with only four times the wing surface — still it is conceivable that a flock of small birds could sustain a heavy load divided equally among them, and it is obvious that in this case the ratio of weight to wing surface would be the same for the whole flock as for the individual bird. If then we build our large structure by combining together a number of small structures each light enough to fly, instead of simply copying the small structure upon a larger scale, we arrive at a compound or cellular structure in which the ratio of weight to supporting surface is the same as that of the individual units of which it is composed, thus overcoming entirely the really valid objections of Professor Newcomb to the construction of large flying-machines.

In my paper upon the tetrahedral principle in kite structure, I have shown that a framework having the form of a tetrahedron possesses in a remarkable degree the properties of strength and lightness. This is especially the case when we adopt as our unit structure the form of the regular tetrahedron, in which the skeleton frame is composed of six rods of equal length as this form seems to give the maximum of strength with the minimum of material. When these tetrahedral frames or cells are connected together by their corners they compose a structure of remarkable rigidity, even when made of light and fragile material — the whole structure possessing the same properties of strength and lightness inherent in the individual cells themselves.

The unit tetrahedral cell yields the skeleton form of a solid, and it is bounded by four equal triangular faces. By covering two adjoining faces with silk or other material suitable for use in kites, we arrive at the unit "winged cell" of the compound 420 kite; the two triangular surfaces, in their flying position, resembling a pair of wings raised with their points upward, the surfaces forming a dihedral angle. (*A,* Plate XIII.) Four of these unit cells, connected together at their corners, form a four-celled structure, having itself the form of a tetrahedron containing in the middle an empty space of octahedral form, equal in volume to the four tetrahedral cells themselves. (*B,* Plate XIII.) In my paper I showed that four of these four-celled structures connected at their corners resulted in a sixteen-celled structure of tetrahedral form, containing, in addition to the octahedral spaces between the unit cells, a large central space equivalent in volume to four of the four-celled structures. (*C,* Plate XIII.) In a similar manner four of the sixteen-celled structures connected together at their corners form a sixty-four-celled structure. (*D,* Plate XIII.) Four of the sixty-four-celled structures form a two hundred and fifty-six-celled structure, etc., etc., and in each of these cases an empty space exists in the center, equivalent to half of the cubical contents of the whole structure, in addition to spaces between the individual cells, and minor groups of cells.

Kites so formed, exhibit remarkable stability in the air under varying conditions of wind, and I stated in my paper that the kites which had the largest central spaces seemed to be the most stable in the air. Of course these were the structures that were composed of the largest number of unit cells; and I now have reason to believe that the automatic stability of these kites depends more upon the number of unit cells than upon the presence of large empty space in the kites; for I have found, upon filling in these empty spaces with unit cells, that the flying qualities of a large kite have been greatly improved. The structure, so modified, seems to fly in as light a breeze as before but with greatly increased lifting power; while the gain in structural strength is enormous.

I had hitherto supposed that if cells were placed directly behind one another, without providing large spaces between them, comparable to the space between the two cells of a Hargrave box kite, the front cells would shield the others from the action of the wind, and thus cause them to lose their efficiency; but no 421 very marked effect of this kind has been observed in practice. Whatever theoretical interferences there may be, the detrimental effect upon the flying qualities of a kite are not, practically, obvious; while the gain in structural strength and in lifting power outweigh any disadvantages that may exist. I presume, that there must be some limit to the number of cells that can be placed in close proximity to one another without detrimental effect; but so far my experiments have not revealed it.

To test the matter, I put together into one structure all the available winged cells I had in the laboratory — 1300 in number. These were closely attached together without any other empty spaces in the structure than those existing between the individual cells themselves when in contact at their corners. The resulting kite, known as “The Frost King,” consisted of successive layers, or strata of cells, closely superposed upon one another. (See Plate XIV.) The lowest layer, or floor of the structure, consisted of 12 rows of 13 cells each. The cells forming each row were placed side by side attached to one an other by their upper corners; and the 12 rows were placed one behind the other, the rear corners of one row being attached to the front corners of the row immediately behind. The next stratum above the floor had 11 rows of 14 cells; the next, 10 rows of 15 cells; etc., — each successive layer increasing in lateral dimensions and diminishing in the fore and aft direction; so that the top layer, or roof, consisted of a single row of 24 cells placed side by side. One would imagine that a closely packed mass of cells of this kind — 1300 in number — would have developed some difficulty in flying in a moderate breeze if the cells interfered with one another to any material extent: but this kite not only flew well in a breeze estimated at not more than about 10 miles an hour because it did not raise white-caps, but carried up a rope-ladder, several dangling ropes 10 and 12 meters long, and more than 200 meters of manilla rope used as flying lines, and in addition to all this, supported a man in the air. (See Plate XV.)

The whole kite, impedimenta and all, including the man, weighed about 131 kgs. (288 lbs.); and its greatest length from side to side was 6 meters at the top and three meters at the 422 bottom. The sloping sides measured 3 meters and the length from fore to aft at the square bottom was 3 meters. It is obvious that this kite might be extended laterally at the top to twice its length without forming an immoderately large structure. It would then be 12 meters on the top (39 ft.) and 9 meters on the bottom from side to side, without changing the fore and aft dimensions, or the height. It would then contain more than double the number of cells and so should be able to sustain in the air more than double the load; so that such a structure would be quite capable of sustaintng both a man, and an engine of the weight of a man, and yet be able to fly as a kite in a breeze no stronger than that which supported the “Frost King.”

An engine of the weight of a man could certainly impart to the structure a velocity of 10 miles an hour, the estimated velocity of the supporting wind, and thus convert the kite into a free flying-machine. The low speed at which I have been aiming — for safety's sake — is therefore practicable.

In the “Frost King” and other kites composed exclusively of tetrahedral winged cells, there are no horizontal surfaces (or rather surfaces substantially horizontal as in ordinary kites), but the framework is admirably adapted for the support of such surfaces. Horizontal aeroplanes have much greater lifting-power than similar surfaces obliquely arranged as in the tetrahedral construction, and I have made many experiments to combine horizontal surfaces with winged cells, with greatly improved results so far as lifting-power is concerned. But there is always an element of instability in a horizontal aeroplane, especially if it is of large size; whereas kites composed exclusively of winged cells are wonderfully steady in the air under varying conditions, though deficient in lifting-power; and the kites composed of the largest number of winged cells seem to be the most stable in the air.

In the case of an aeroplane of any kind the center of air-pressure rarely coincides with the geometrical center of surface, but is usually nearer the front edge than the middle. It is liable to shift its position, at the most unexpected times, on account of some change in the inclination of the surface or the direction of 423 the wind. The change is usually small in steady winds; but in unsteady winds great and sudden changes often occur.

The extreme possible range of fluctuation is, of course, from the extreme front of the aeroplane to the rear, or *vice versa* , and the possible amount of change, therefore, depends upon the dimensions of the aeroplane — especially in the fore and aft direction. With a large aeroplane the center of pressure may suddenly change to such an extent as to endanger the equilibrium of the whole machine. Whereas, with smaller aeroplanes, especially those having slight extension in the fore and aft direction, the change, though proportionally as great, is small in absolute amount. Where we have a multitude of small surfaces well separated from one another, as in the tetrahedral construction, it is probable that the resultant center of pressure for the whole kite can shift to no greater extent than the centers of pressure of the individual surfaces themselves. It is, therefore extremely unlikely that the equilibrium of a large kite could be endangered by the shifting of the centers of pressure in small surfaces within the kite. This may be the cause of the automatic stability of large structures built of small tetrahedral cells. If so, one principle of stability would be: *Small surfaces — well separated — and many of them.* The converse proposition would then hold true if we desired to produce instability and a tendency to upset in a squall — namely: *Large surfaces — continuous — and few of them.*

Another source of danger with large continuous surfaces is the fact that a sudden squall may strike the kite on one side, lifting it up at that side and tending to upset it. But the compound tetrahedral structure is so porous, that a squall passes right through and lifts the other side as well as the side first struck; so that the kite has not time to be upset before the blow on one side is counterbalanced by a blow on the other. I have flown a Hargrave box kite simultaneously with a large kite of many tetrahedral cells in squally weather for the purpose of comparing them under similar conditions. The tetrahedral structure often seemed to shiver when struck by a sudden squall, whereas the box kite seemed to be liable to a swaying or tipping motion that would be exceedingly dangerous in a structure of large size forming part of a flying machine.

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Another element of stability in the tetrahedral structure lies in the fact that the winged surfaces are elevated at a greater angle above the horizon than 45°.

Supposing the wings of a cell to be opened out until they are nearly flat — or at least until they each make a comparatively small angle with the horizon — say 20° — then if, from any cause, the cell should tip so as to elevate one wing (say to 25°) and depress the other (say to 15°) then the lifting-power of the wind will be increased upon the elevated wing and diminished on the depressed wing, so that there would be no tendency to a recovery of position, but the very reverse. The pressure of the wind would tend to increase the tipping action, and favor the production of oscillation and a tendency to upset. The lifting-power of the wind upon a surface inclined at 10° is less than at 20°; and greater at 25° than 20°. The more the wings are opened out, and the flatter they become, the more essentially unstable is the arrangement in the air.

Now suppose the wings to be raised until they are nearly closed, or at all events until they make a small angle with the vertical (say 70° from the horizontal), then if from any cause the cell should tip so as to elevate one wing (say to 75°) and depress the other (say to 65°), the lifting-power of the wind will be increased upon the depressed wing and diminished on the elevated wing; for the lifting-power of the wind is greater at 65° than at 70° and less at 75°. Thus the moment a tipping action begins the pressure of the wind resists it, and an active force is invoked tending to restore the structure to its normal position. The more the wings are raised, and the more they approach the perpendicular position the more stable essentially is the arrangement in the air.

The dividing line between these two opposite conditions seems to be drawn about the angle of 45°. As the tetrahedral wing-surfaces make a greater angle than this with the horizontal they constitute an essentially stable arrangement in the air; whereas a horizontal surface represents the extreme of the undesirable unstable condition.

These considerations have led me to prefer a structure composed of winged tetrahedral cells alone, without horizontal surfaces 425 either large or small, although the lifting-power is less than when horizontal surfaces are employed, because the factor of safety is greater. One of the chief causes that have led to disasters in the past has been lack of stability in the air. Automatic stability under varying conditions is surely of the very first consequence to safety, for what would it profit a man were he to gain the whole world and lose his own equilibrium in the air? A kite composed exclusively of multitudinous winged-cells seems to possess this property of automatic stability in a very marked degree. If then its lifting-power is sufficient for our purpose there is no necessity for the introduction of a factor of danger by the addition of horizontal surfaces. Of course the addition of such surfaces would enable us to secure the desired lifting-power with a smaller and therefore lighter structure, and this would be of advantage if we could be sure of its stability in the air.

In employing tetrahedral winged-cells alone, upon the hollow plane of construction in which large empty spaces occurred within the kite, a practical difficulty was encountered arising from the enormous size of the structure required for the support of a man, combined with the increasing weakness of the structure as it increased in size. The discovery that the cells may be closely massed together without marked injurious effects has completely remedied this difficulty; for upon this plan, not only is the structural strength improved by an increase of size, but the lifting-power increases with the cube of the dimensions, so that a very slight increase in the dimensions of a large kite increases very greatly its lifting-power. We now have the possibility of building structures composed exclusively of tetrahedral winged-cells that will support a man and an engine in a breeze of moderate velocity, without the necessity of constructing a kite of immoderate size. The experiments with the "Frost King" made in December, 1905, satisfied me upon this point, and brought to a close my experiments with kites.

Conclusion.

Since December, 1905, my attention has been directed to other points necessary to be considered before an aerodrome of the 426 kite variety can be made; and to the assembling of the materials for its manufacture.

I have had to improve and simplify the method of making the winged-cells themselves. Through the agency of Mr. Hector P. McNeil, Superintendent of the Volta Laboratory, Washington, D. C., who is now taking up the manufacture of tetrahedral cells as a new business, I am now able to obtain cells constructed largely by machinery, and with stamped-metal corners to hold the rods together. The process of tying the cells and parts of cells together had proved to be very laborious and expensive; and the process was not suited to unskilled persons. By the new process most of the work is done by machinery, and no skill is required to connect the cells together.

I have also had to go into the question of motor construction, a subject with which I am not familiar; and while waiting for the completion of the material required for the aerodrome I have been carrying on experiments to test the relative efficiency of various forms of aerial propellers. I have also been occupied with the details of construction of a supporting float adapted for propulsion over the water as a motor boat, and also adapted to form the body of the flying-machine when in the air.

Of course it would be premature for me to enter into any description of experiments that are still in progress, or to submit plans for an aerodrome which are still under discussion. I shall therefore simply say in conclusion that I have recently been making experiments in propelling, by means of aerial propellers, a life-raft supported, catamaran fashion, on two metallic cylinders. The whole arrangement, with a marine motor on board, is exceedingly heavy, weighing over 2,500 pounds; and it is sunk so low that the water level rises at least to the middle of the supporting cylinders, so that the raft is not at all adapted for propulsion, and cannot attain great speed. The great and unnecessary weight of this machine has led to an interesting and perhaps important discovery that might have escaped attention had the apparatus been lighter and better adapted for propulsion.

Under the action of her aerial propellers, this clumsy raft is unable to attain a higher speed than four miles an hour; and yet 427 she is able to face a sixteen-mile white-cap breeze, and make headway against it, instead of drifting backwards with the wind. Under such circumstances her speed is materially reduced; but the point I would direct attention to is this, that she is not stopped by a current of air moving with very much greater velocity than her maximum possible speed in a calm. Of course there would be nothing remarkable about this if her propellers were acting in the water instead of the air, but they were not. They acted exclusively in the air, and the water was only an additional resistance to be overcome.

It is worthy of note in this connection that the rapid rotation of the propellers yield a theoretical efficiency of thirty of forty miles an hour, and that the mass of the machine and the resistance of the water drag this down to an actual performance of only four miles, so that at first sight it appears probable that the effect noted may be a result of the greater slip of the propellers acting in a calm. I am inclined to think however that this explanation is insufficient; and would suggest the following as more probable.

The enormous mass of the moving body enables it to acquire very considerable momentum with slight velocity; whereas, the opposing current of air has such slight mass, that it cannot acquire an equal momentum with a very much higher velocity.

If two bodies of unequal mass, moving with equal but opposite velocities, come into collision with one another, then the heavier body will not be completely stopped by the lighter. It will make headway against the resistance of the other even though the lighter should possess superior velocity, provided, of course, that it has a sufficient superiority of mass. We are here dealing with momentum (*mv*), not velocity (*v*) alone. The body having the greatest momentum will be the victor in the struggle whatever the actual velocities may be.

The suggestiveness of this result lies in its application to the flying machine problem. A balloon, on account of its slight specific gravity, must ever be at the mercy of the wind. In order to make any headway against a current of air it must itself acquire a velocity superior to the wind that opposes it. On the other hand it is probable that a flying machine of the heavier-than-air 428 type, at whatever speed it moves, will be able to make headway against a wind of much greater velocity, provided its momentum is greater than the momentum of the air that opposes it.

DISCUSSION OF DR. BELL'S ADDRESS BY CHARLES M. MANLY.

It is a notable sign of the kind of attention aeronautical work is now attracting, that one who has to his credit the accomplishment of such big things as Dr. Bell has, should become so actively engaged in it. As Dr. Bell has already pointed out, the world owes much to Mr. Langley for taking hold of the subject when it was looked upon as the wild dream of cranks and enthusiasts and by putting it on a scientific basis made it seem worthy of serious attention. It is no less fortunate that we have to-day such men as Dr. Bell actively engaged in the construction of large man-carrying machines, for the influence of their example causes the work to be looked on by the public more and more seriously all the time.

Dr. Bell has pointed out that one of the advantages possessed by such a slow speed aerodrome as he will be able to construct by utilizing his important invention of tetrahedral cells, is the possibility of anchoring such a machine and having it maintained at a height through its ability to fly as a kite. This suggests the superiority which such a machine will possess not only as regards safety in case of a break-down of the machinery, but also as regards its use as a war machine. The ability to anchor and remain steadily over a given point will enable the operator or operators to thoroughly study and map out fortifications and the disposition of field forces, as there is very slight probability of so small an object as an anchor rope being discovered by the enemy, and even if it should be, the ability of the operator to cut the rope would render him comparatively free from capture.

As a war machine Dr. Bell's tetrahedral plan of cellular construction for the surfaces would also I think present another very great advantage. Such a machine might be badly riddled with shot and yet be able to maintain very good equilibrium, while a machine having large units of surface with large parts in the frame work of its surfaces, would be very seriously crippled should a chance shot disable one of the main supports on one side.

It may not be amiss to call attention also to the fact that the operator on any aerodrome or balloon when at a considerable height can plainly see submarine boats at any depth in the water. Such machines can therefore be used for determining the number of submarine craft in 429 the enemy's force of harbor defenses, and by keeping the machine circling above a battleship or a fleet of ships, the possibility of attack by submarine boats would be very greatly lessened. In fact I should think that with Dr. Bell's multicellular machine there would be no great difficulty in maintaining the operator in the air for hours by simply flying the machine as a kite anchored to the ship.

I trust that Dr. Bell will pardon me for not agreeing with the explanation he suggested of the very interesting fact noted in regard to the propulsion of the “Catamaran Life Raft” by means of aerial propellers, namely that the raft advanced against a 16-mile breeze, although in a calm it was able to make only something like four miles an hour.

It seems to me that this ability of the raft to advance against a 16-mile wind is not due to the difference between the momentum of the raft and the momentum of the air, but to the fact that the raft presents very little resistance to the wind, while the propeller, being revolved at a high rate of speed by the engine, tends to advance in the air at a speed proportionate to its pitch multiplied by its number of revolutions in a given time; and I have no doubt that the raft would have advanced against any wind of a velocity less than that which would be created by the slip of the propeller revolving in still air at the same speed as when driving the raft. In other words, if the propeller had a pitch, let us suppose, of one foot (that is, tended to advance through the air one foot for each revolution, or forced the air backwards one foot for each revolution), such a propeller revolving at the rate of a thousand revolutions a minute would in a calm create a back wind of a thousand feet per minute, and of course a propeller of two feet pitch would create a back wind of two thousand feet per minute when revolving at the same speed. Such a propeller, then, of two feet pitch, revolving at this speed, when mounted on a raft should be able to prevent the raft being blown backwards in a wind of somewhere near two thousand feet per minute. I have no doubt that the back wind due to the propeller in Dr. Bell's experiment was of an even higher velocity than two thousand feet per minute.

Few of us can conceive of the affairs of the world being very different from what we are accustomed to. But there are certain definite effects which we can be fairly confident will follow definite changes. I am not a prophet nor the son of a prophet, but I feel safe in venturing a conservative prediction in regard to one of the effects of aerodromic work in the next few years. We may not be able to make it a general vehicle of transportation, as some enthusiasts predict; I myself, 430 indeed, while unwilling to define the limits of the possible, certainly do not expect such results very soon. But I have no hesitation in asserting that the attainment of the ability to fly say three hundred miles, — a degree of success now practically certain to be attained within five years — will, at whatever risk of danger to the aeronaut, have as important an effect on warfare as the advent of wireless telegraphy, and a far greater one than the perfecting of the submarine boat or the Whitehead torpedo, both of which even now are causes of the greatest concern to the officers of even the last, and largest, and most expensive battleship.

It is interesting in this connection to learn, what I have just been told on good authority, that a prominent admiral of the navy who has just retired is planning to devote his time to a thorough study of aerodromics, foreseeing as he probably does the early advent of the flying war machine, which there seems ample ground for believing will prove to be the most important single step in the progress of the art of war.

I am pleased to hear Dr. Bell state publicly his confidence in the accuracy of the reports of the success of the Wright brothers, for I myself have had every confidence in them and have thoroughly appreciated the motives which have prompted them to withhold a public demonstration of their machine until business arrangements can be completed which will enable them to reap the financial profits which their success so richly deserves.

I trust that I shall be pardoned for emphasizing Dr. Bell's statement as to the importance of the fact that the Wright brothers have flown not only once but many times. The fact that a machine has flown successfully and carried a man not only a few hundred feet but something like twenty-five miles, will, when its significance is realized, have the greatest effect on the future progress of the work.

I have always wondered why it is that the more prominent polar explorers have been able to secure very large sums of money for use in their attempts to reach the north pole, yet no public benefactor has seemed ready to render substantial financial assistance in the solution of this problem of opening up for mankind the great aerial highway, which to me at any rate, seems of such vast importance to the world. The only reason I could assign for this has been, that while the existence of such a point as the pole is capable of mathematical demonstration, the possibility of a successful flying machine has seemed a subject not for science but for dreams.

It seems to me however, that the fact that success has already been 431 achieved by the Wright brothers should put the whole problem on a very different footing and convince even the skeptical that the question of success is now merely a question of degree. As people of means who wish to perpetuate their name can do it in no better way than by assisting in a substantial manner in the progress of scientific investigation, they will surely now be ready to furnish the funds necessary to ensure more rapid progress in this work.

We must remember that in these days work of this kind progresses by leaps and bounds. It is barely seven years ago that the first annual automobile show was held in Madison Square Garden, New York. No attempt was made to utilize the galleries of the Garden and practically the entire area of the main floor was given over to a track which was used for demonstrating to the audience the fact that an automobile could be stopped in a very much shorter distance than a horse-drawn vehicle going at the same speed. The management in charge of this show, in order to fill up space, even provided seats which were arranged for the convenience of the visitors. Last winter, just six years after that date, instead of one show occupying only a small portion of the Garden, there were two shows of about equal size held simultaneously in New York, and the one which was held in the Garden not only filled it from cellar to roof, but the streets all around were filled with demonstrating machines, and instead of seats being provided, it was necessary to have policemen to see that the people followed the proper circuit of the building so that the crowd should be kept moving and all might have a chance to view the exhibition. As the outcome of industry which six years ago amounted to nothing, we have in the United States to-day something like ten million dollars invested in approximately 75 manufacturing establishments which, during the year which is just closing, have produced more than fifty thousand machines, and instead of the automobile being ridiculed by the cartoonist as a chimerical dream it has become the chariot of the millionaire and the freight truck of the industrial world, hauling goods and ore from the steamship piers and the mines.

Realizing that this enormous progress has been made in the short period of less than a decade, it is only a pessimist of the deepest dye who would dare predict that the next decade will not see not only enormous strides in the progress of aerodromics, but also the aerodrome itself an important factor in human affairs.

For thousands of years man was content to travel no faster than his ancestors, but the advent of the steam locomotive followed by that of the electric car has quickened the inventive genius of the world to its 432 very core; and man, not content with being confined to travel at a high speed on a definite route marked by parallel steel rails, has quickly taken up the automobile which can follow not only the multitudinous roadways, but, if necessary, blaze out its own way through the fields and woods. Instead of having his ambition satisfied by this multiplication of his possible paths, he still thirsts for more freedom and will not be satisfied until he has opened up for himself access to the highways of the air, which are limitless in all directions and on which speed laws enforced through police traps, if not impossible, will at least be most difficult to maintain and enforce.

While for many years I have felt the deepest interest in aeronautical matters, it was only in 1898 that I first became actively engaged in the work. I had the pleasure and the honor of being associated for some seven years with the lamented Secretary Langley as his assistant in direct charge of the experiments which he conducted at the Smithsonian Institution. Dr. Bell has already referred to the fact that this later work which Mr. Langley conducted was carried on for the Board of Ordnance and Fortification of the War Department. As you are all no doubt aware, it is the custom of the War Department in conducting important tests to exclude not only the general public but also the representatives of the newspapers; and in undertaking this work for the War Department, Mr. Langley made a very definite agreement that the public should be excluded from witnessing the construction of the aerodrome and the tests of it, though in the interests of science he retained the privilege of later publishing whatever part of the work he might deem of importance to the scientific world. It could not be foreseen at that time that the carrying out in good faith of this agreement would bring upon him the bitter animosity of the whole corps of American newspaper writers who would vent their ill will in ridicule and in censure for failure to achieve complete success.

As those of you who followed the newspaper reports during the experiments in the summer and fall of 1903, will recall, the large houseboat, on which were stored both the large machine and a duplicate of it on a smaller scale, was carried down the Potomac River in July and anchored at a point about forty miles from Washington. The first experiments which were made were conducted with this model which was an exact duplicate of the larger machine but of exactly one quarter the linear dimensions. The object of the tests with this model was to determine whether the balancing of the large machine had been correctly calculated from the results of the many previous tests of the steam driven models of approximately the same size but embodying 433 important differences in certain details. I will not burden you with an account of the long series of exasperating delays encountered, delays almost entirely brought about by the very unusual weather conditions which could not be foreseen and provided against; I will only say that the several newspaper representatives who went down the river early in July and remained stationed there for several months in a malarial district on the Virginia shore, and who had to row somewhat over a mile and a half in order to get within close range of the house-boat which was anchored in the middle of the river, were naturally not very favorably influenced either by the fogs and high winds or by their necessary exclusion from all real knowledge of the work going on within the house-boat.

I cannot emphasize too strongly that there was neither fault in design nor inherent weakness in any part of this large aerodrome. The whole machine had been subjected to the most severe tests and strains in the Institution shops in the endeavor to find any possible points of weakness and had shown itself able to withstand any strain it would meet in the air.

The experiments themselves convinced both Mr. Langley and myself that it would have been better to have conducted them over land rather than over water and we should thereby have avoided a great deal of expense and the major part of the delays and accidents which were encountered; yet it must be remembered that in work of this kind experiment is the only sure guide and that aftersight is always much clearer than foresight. It is my personal opinion that had the experiments been conducted over the land instead of over the water, not only would the funds which proved inadequate have been more than ample, but success would have been achieved as early as 1902 instead of what the public has judged to be failure in 1903.

Dr. Bell has told you that in the last experiment the aerodrome was broken to pieces through the ignorance and carelessness of the tugboat men in getting it out of the water. It was almost heart-breaking to look at the wreck that they made of it; but although Mr. Langley found himself without funds for making further experiments with the machine, yet at my earnest solicitation he allotted sufficient money to enable the frame to be repaired so that it is practically as good as new and stands to-day completely assembled with its engine and everything to enable it to fly except a new set of supporting surfaces.

It has been generally supposed that the work has been abandoned and this idea has been strengthened by Mr. Langley's death, but I think I can assure you that the work is not abandoned but merely temporarily 434 suspended, for it is my purpose, at the earliest moment that I can possibly spare the time for it, to reëquip the aerodrome with proper supporting surfaces and using the same launching apparatus, to give the aerodrome a fair trial, this time over the land instead of over the water, when I feel very certain that it will fully demonstrate the correctness of its design and construction and crown Mr. Langley's researches with the success which they so richly deserve, and I trust that the day that this will be achieved is very near at hand. It was the launching apparatus, all will remember, which in both of the experiments caused the accidents that prevented any test of the aerodrome itself. These accidents were not due to defects in the design or fundamental construction of the launching apparatus, for the smaller apparatus of exactly the same design had been used more than thirty times for launching the smaller machines and without a single failure. Certain minute defects in the releasing mechanism were the sole cause of the trouble.

It has been very generally supposed that in his experiments Mr. Langley used exclusively what may be called “single tier” surfaces and that he did not recognize that the superposing of the lifting surfaces presented certain great advantages not only as regards ease of construction and strength, but also in reducing the size of the machine. This general impression is due to the fact that all of the photographs of the machines in flight which he published officially, and also those published by the newspapers, have shown the machine as equipped with “single tier” surfaces. I may say however that as early as 1890 and constantly from that time until the work was temporarily suspended in 1903, Mr. Langley experimented with superposed surfaces, the first experiments of course being with very small models having their motive power furnished by means of stretched or twisted rubber. The same large steam driven models which flew so successfully in 1896, the first flight of which Dr. Bell has just spoken of having witnessed, were in 1899 equipped with superposed surfaces and were tested in free flight during the months of July and August.

The quarter-size model of the large aerodrome driven by a gasolene engine which was first tested in 1901 and later in the summer of 1903, was also equipped with superposed surfaces, but in the test of August, 1903, which was witnessed by the newspaper representatives, the “single tier” surfaces were used. The prime reason that the large aerodrome was equipped with the “single tier” surfaces was that the best flights of the models were with such surfaces, and although in the beginning it was planned to build superposed surfaces for the large 435 machine later, the early depletion of the funds provided by the Board of Ordnance and Fortification made it imperative to utilize what had already been constructed, as it was with the greatest reluctance that Mr. Langley continued the work with the funds of the Institution, and all expense which could be avoided was carefully guarded against. I have thought it well to mention this fact as I have had many inquiries as to why it was that Mr. Langley never realized that the superposed type of construction for the supporting surfaces presented important advantages.

It was my duty while connected with the Smithsonian Institution to prepare answers to the large number of letters on aeronautical subjects which were constantly received. While some of the writers sought advice, others offered it; and a large number of the letters indicated that the writers believed that the problem of constructing a successful machine required the discovery of some “secret.” In view of this experience, I have thought that it might not be amiss to emphasize, that there is no “secret” which needs to be discovered in order to build a successful machine, but that success is to be achieved by laying out a good design based on a proper knowledge of the laws of aerodromics as at present known, next by giving the greatest care to constructing the parts as strong as possible for the permissible weight, and then trying the machine, not once only, but again and again under conditions presenting the least possible danger to the operator.

In this connection attention may be called to the fact that when a machine is planned and the weight of the different parts is allotted, so that the total weight shall not exceed a certain proportion relative to the supporting area, the experimenter need not be surprised to find, when he has completed his machine that it weighs forty or fifty per cent. more than he has calculated; for in carrying out the innumerable details of construction small increases in weight at almost every point finally increase the total weight surprisingly.

In all of the accounts which I have lately seen of the experiments of the Wright brothers, no mention has been made of the fact that the success of the Wrights has been built on the very valuable work of Mr. Chanute, who for many years carried on at his own expense work in the construction and testing of gliding machines, and who I understand, not only furnished the Wright brothers with the design for their first gliding machine, but also placed at their disposition his own machines with which they made their initial gliding experiments. There is perhaps no one who has made a closer study and has a more thorough understanding of the whole subject of aerodromics than Mr. 436 Chanute, and I should like very much to see him given due credit for the very important work which he has done.

DISCUSSION BY PROF. A. F. ZAHM, OF THE CATHOLIC UNIVERSITY OF AMERICA.

I fully concur with Dr. Bell in the opinion that aerial locomotion is practicable, and is likely soon to be of great moment in the affairs of the world. For the progress of this science, during the past decade or two, has been as positive, as continuous, as substantial as that of any branch of engineering or of architecture. Constantly and quietly, in various parts of the world, men have grappled with the difficulties of this apparently hopeless enterprise, and now, I believe, we are about to enjoy the fruitful and splendid issue of their labors.

The subject of aerial locomotion may be divided into four main branches: first, the science of captive and free balloons; second, the science of motor balloons; third, the science of gliding and soaring machines; fourth, the science of dynamic flying-machines. Each of these has had its ardent advocates, and each is, I believe, practically feasible.

The first branch, or that of captive and free balloons, is already a practical science, inasmuch as such balloons perform substantially the functions for which they are designed. The captive balloon can be sent aloft safely in all kinds of weather for taking observations, and making maps of the neighboring region, even in winds of upwards of forty miles an hour. The free balloon, likewise, is comparatively safe when made by an experienced manufacturer and managed by a properly trained pilot. Such balloons may be kept aloft for days, or even weeks, traversing, in that time, hundreds of miles, or possibly the width of a continent, if the wind be favorable. But, though we grant the practicability of balloons of this type, it must be said also that their functions are limited; their chief usefulness thus far being for the study of the atmosphere, for observations of the land beneath, for military operations, for public exhibitions, and now recently, for racing and sport.

The ideal of the motor balloon is more important and more difficult, though it also seems about to be realized. The function of such craft is to go forth in all kinds of ordinary weather, to run in all directions, with or against the wind, scores of miles at a stretch, and to remain under perfect control. Salverda has shown, by reference to the yearly wind records at Paris, that aerial navigation may be practically realized, for that locality, when a vessel can be driven twenty-eight miles an hour. Is such achievement possible? More than a decade ago 437 theorists demonstrated mathematically that this speed, and even higher, was attainable by appliances then known. Now apparently the inventors, taking a lesson from Santos Dumont, have caught up with the computers, and are producing the high speed balloons. On the third of this month, an eye witness told me that he saw Count von Zeppelin's air-ship fly about Lake Constance at a speed of twenty-eight miles an hour, independently of the wind, and that she obeyed her rudder as perfectly as a boat on the water. It is reported that the inventor has deduced from these experiments that a larger vessel will operate still more effectively, that an air-ship of this type can be made to carry fifty passengers at a speed of more than thirty miles an hour. Count von Zeppelin writes that his present balloon, which is 410 feet long and 38 feet in diameter, has attained a speed of 33.5 miles an hour, and is able to go 1,860 miles through the air at a speed of 31 miles an hour, or 3,000 miles at a speed of 25 miles an hour, without stopping for supplies. To match this achievement in Germany, let me add that the French Government has just accepted the second Lebaudy motor-balloon, and has ordered one more like it, thus adding three modern air-ships to her aerial equipment. Such facts may give us at least a little faith in aerial locomotion of the second kind.

The goal of the gliding and soaring machines is to travel through the air on motionless wings, without the aid of gas or motive power, by the sole aid of wind and gravitation; not only to glide downward, but also to soar up to the clouds, and sweep over vast territories, as do the condor and the albatross. To some people this seems absurd; but there are the vultures and the gulls performing the impossible every day. Humboldt assures us that the condor can soar from the Pacific to the heights of Cotopaxi and Aconcagua without wing-beat. Here is a splendid field of research which thus far has remained practically unexplored.

Unfortunately, I can not quote an instance of real soaring by man; that is to say, gliding to an indefinite height and distance, without the use of motive power. Still, from the mechanical nature of the performance, I believe it is feasible. Dr. Langley was so convinced of the possibility of this kind of flight that he looked forward to the time when men would soar over vast distances, and possibly circumnavigate the globe without the expenditure of motive power, save in those regions of the atmosphere where there might be an extended calm or downward trend of the wind.

Two years ago the Wright brothers compared their power of aerial gliding with that of a vulture in North Carolina, among the Kill-Devil 438 sand hills. On a day when there was little or no wind, they observed a buzzard tobogganning down the atmosphere parallel to the sloping sand and very near to it. Where the slope was steep enough the bird could glide indefinitely without wing-beat, but where the incline was too gentle, say seven degrees or less, the buzzard had to flap a little to maintain its flight. Having carefully noted a considerable stretch of sand where the bird could barely sail without flapping, they mounted their glider and skimmed over the same slope without motive power. From such experiments they concluded that they could glide fully as well as the buzzard, and possibly a trifle better. In other words, if they were placed on a perch with the bird in competition, in a large closed room, they would probably win the prize for long distance gliding.

In one other feat, also, they imitated the vulture. They hovered motionless above a sand slope for 59 seconds, neither rising nor falling, nor advancing nor receding. In this case, of course, the wind had a slightly upward trend, say of seven or more degrees, just as must be the case when any bird floats fixed and motionless in the air.

I put this question to them recently: “After beating the buzzard in the art of gliding, did you try to beat him in the art of soaring up to the clouds?” They replied that nothing would have given them more pleasure; but their power machine, on which they had worked so arduously, and so long, was ready for its first test, and Christmas was just at hand. So they went out in a bitter gale, launched their motor flying machine in the teeth of a tumultuous thirty-mile wind, and flew half a mile through the air, or three hundred and some feet over the ground. Thus ended their gliding and thus began their dynamic flight.

But they still envy that feathered professor of the atmosphere, and still have confidence that they may, to some extent, acquire his fascinating art. If they could dispose of their present power machine, doubtless they would return again to the sand-hills and plunge pell-mell into the soaring business.

As to the fourth type, or the motor flying-machine, I need add little to the excellent summary given by Dr. Bell. Without radical improvement, such machines may be driven through the air with the speed of the eagle, and made to carry several hundred pounds burden. The Wright brothers, in their recent communication to the Aero Club of America, conclude with these words: “It is evident that the limits of speed have not as yet been closely approached in the flyers already built, and that in the matter of distance the possibilities are even more encouraging. Even in the existing state of the art, it is easy to design 439 a practical and durable flyer that will carry an operator and supplies of fuel for a flight of over 500 miles at a speed of 50 miles an hour.”

In a great conflict like the recent oriental war, one such machine could do more reconnoitering than 50,000 armed men. For, in a few hours, it could completely survey and snap-shot the enemy's main field of operations, though covering hundreds of square miles. A fleet of such machines, armed with bombs and fire pellets, could devastate the whole of an enemy's border, both towns and villages, unless opposed by other flyers. Possibly, also, a fleet of this kind could protect a nation's seaboard against the attack of battleships, unless the latter were accompanied by an aerial squadron. Therefore, if one great nation keep flyers, all the world-powers must have them.

But this seems like hunting for trouble with a search light just before daybreak. Whatever be the mission of the flying-machine, I think we may say of it as the English do: “The thing is bound to come, whether we like it or not.” “And damned be he who first cries hold!”

As to Dr. Bell's researches in this interesting and now popular field of inquiry, I would say, first, that every earnest friend of science should be very grateful to him for lending his illustrious name to a much ridiculed pursuit, at a time when it jeopardized one's peace and good name publicly to promote mechanical flight. I well remember with what apprehension Mr. Chanute consented to become chairman of the first international conference on aerial navigation in this country. And we all too well remember the attitude of many people toward Dr. Langley's painstaking and unobtrusive investigations. The Wright brothers, also, experienced hostile treatment in certain quarters before their success was known. Even after the news of their splendid flights of last year had been circulated privately among their friends, we heard many apparently intelligent dogmatists assert that it is not the design of Providence, or of Nature, that a human being should fly; and that, furthermore, the performance is manifestly impossible. This is another illustration of the value of public opinion in matters of technical import. But fortunately, the destinies of science are not dominated wholly by the vote of the majority, not yet by grand officials, whether legislative or executive, else, I fear we never should have either a science or an art of aerial locomotion.

Another service for which we may thank Dr. Bell is his having met publicly, both by model and by argument, a profound objection of the mathematicians, based on that ancient Euclidean theorem connecting the surfaces and volumes of similar figures with certain powers of their Proc. Wash. Acad. Sci., March, 1907. 440 homologous linear dimensions. Dr. Bell did not deny the law, as a chagrined or an angry person might; but, like a shrewd man of affairs, he admitted the law, and discovered a way to evade it.

Now that his reply is familiar to us, it may seem amusing that people urged the Euclidean objection so strongly; but the fact is that many persons, besides Professor Newcomb, advanced it as an argument against the practicability of mechanical flight. In the middle eighties an eminent geologist made it the basis of a magazine article, in which he proved, with fine eloquence, that it is impossible for a human being ever to fly. He further supported his contention by a vigorous biological argument, and possibly also by a theological or teleological one, I do not remember. He asserted that nature had tried for centuries to produce a flying creature as heavy as a man, but had failed; therefore, it is utterly impossible for man to achieve mechanical flight. By diligent experimentation she had tested and adopted the strongest possible materials, she had developed the most powerful motor for a given weight, she had employed the most favorable shapes and the most efficient mode of propulsion. But what was the outcome? Her largest flyer weighs hardly so much as a human dwarf. The ostrich is the limit. The ostrich is the living witness of nature's failure. And that picturesque old reptile, with the twenty-foot wings, that soared so grandly over the Cretacean seas, remains to-day the fossil proof of nature's utmost capacity, and therefore also of man's. Such argumentst such prettily woven sophistries, such quaint immemorial cobwebs, have Dr. Bell and his associates brushed reverently from the pages of science.

There are many features of Dr. Bell's remarkable kites, both structural and aerodynamic, that merit most careful attention; more particularly the relation of the forward resistance to the total upward lift, the effectiveness of the provision for automatic stability and equilibrium in all kinds of tumultuous winds, the distribution of stresses in the frame, and of the impulsive pressures over the sustaining surfaces. But these topics seem to me more suitable for experimentation than for abstrac, analysis.

One interesting phenomenon, however, I will notice in closing. Dr. Bell relates that his floating kites, which in calm weather, could advance but four miles an hour, still continued to make headway against a sixteen-mile wind. The momentum of the craft might maintain this forward motion for a few seconds, but not for a considerable period. For the total momentum in any direction is equal to the initial momentum plus the impulse of the resultant force in the line of progression. Or, in the language of algebra, 441 $mv = m_0 v_0 + (F - F')t$ in which mv is the momentum at the time t, $m_0 v_0$ the initial momentum, $F - F'$ the resultant of the average propulsive and opposing forces. If mv is positive for large values of t, the equation shows that F must at least equal F'. But Dr. Bell observed, that the kites continued always to advance, or that *mv* remained positive. Therefore the propulsive force continued, on the average, at least equal to the resistance. In other words, it was the propeller thrust, rather than the momentum, that maintained the indefinite forward progression.

But how, it may be asked, could the propeller thrust maintain headway against a sixteen-mile wind, if, in calm weather, it could support a speed of only four miles an hour? I would answer: first, that the water resistance was not greater in the sixteen-mile wind, but probably less; second, that the propeller thrust might be not very different in a calm and in a sixteen-mile wind, as Maxim found. This latter point Mr. Manly can elucidate readily from his extensive study of both the theory and actual working of screw-propellers.

It is well for the world when a man of Dr. Bell's fertility espouses some favorite science. He took up the kite as a toy, and now presents these wonderful structures; light and beautiful as butterflies, yet strong and stable enough for human life. If next he incline to magnificence, what lovely air-castles will follow! Serenely, one day, may he soar in a gossamer palace, when the blue waves blossom, and the wind sings over the sea!

Appendix A. Details Concerning the Kite “Frost King.”

Number of Cells in the “Frost King.”

Layers of cells. Number of rows. Number of cells in each row. Number of cells in each layer. 1st layer 1 24 24 2d layer 2 23 46 3d layer 3 22 66 4th layer 4 21 84 5th layer 5 20 100 6th layer 6 19 114 7th layer 7 18 126 8th layer 8 17 136 9th layer 9 16 144 10th layer 10 15 150 11th layer 11 14 154 12th layer 12 13 156 Total number of cells, 1,300 442

Dimensions. — Each cell had a side of 25 centimeters, so that the roof, or ridge pole, measured 6 meters extending laterally across the top of the structure. The oblique sides were 3 meters in length; and the bottom, or floor, formed a square having a side of 3 meters. The whole structure constituted a section of a tetrahedral kite — the upper half in fact, of a kite, having the form of a regular tetrahedron with a side of 6 meters.

Weight. — The winged cells composing this structure weighed on the average 13.84 gms. apiece, so that the whole cellular part of the structure which supported all the rest — consisting of 1,300 winged-cells — weighed 17,992 gms.

In addition to this, the kite carried as dead load stout sticks of wood which were run through the structure to distribute the strain of the pull upon the strong parts of the framework — that is, upon the junction points of the cells. The outside edge of the kite was also protected by a beading of wood. The whole strengthening material weighed 9,702 gms., and the kite, as a whole, weighed 27,694 gms. (61 lbs.).

Surface. — I estimate the surface of an equilateral triangle having a side of 25 centimeters, as about 270.75 square centimeters. In which case the silk surface of a single winged-cell, consisting of two triangles, amounts to 541.5 square centimeters; and the actual silk surface employed in 1,300 cells equals 70.3950 square meters (757.7 sq. ft.).

The surfaces are all oblique; and if we resolve the oblique surfaces into horizontal and vertical equivalents (supporting surfaces and steading surfaces) we find that the resolved horizontal equivalent (supporting surface) of a single winged cell forms a square of which the diagonal measures 25 centimeters, and this is equivalent to a rectangular parallelogram of 25 × 12.5 cm., having an area of 312.5 square centimeters.

Thus an actual silk surface of 541.5 square centimeters arranged as the two wings of a winged cell, yields a supporting surface of 312.5 square centimeters.

In kites, therefore, composed exclusively of tetrahedral winged cells, each having a side of 25 centimeters, the area of supporting surface bears the same proportion to the actual surface as the numbers 3,125 to 5,415; or 1 to 1.7328.

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Supporting surface/Actual surface = 1/1.7328.

A simple way of calculating the amount of supporting surface in such structures is to remember that there are 32 cells to the square meter of supporting surface. Therefore, the 1300 cells of the kite “Frost King” had a supporting surface of 40.6250 square meters (437.3 sq. ft.).

Ratio of Weight to Surface. — The actual silk surface employed in the “Frost King” was 70.3950 square meters (757.7 sq. ft.), the weight of the kite was 27,694 gms. (61 lbs.), so that on the basis of the actual surface, the flying weight was 393.4 gms. per square meter (0.08 lbs. per sq. ft.).

But for the purpose of comparing the flying weight of a tetrahedral kite with that of other kites in which it is usual to estimate only the aeroplane surfaces that are substantially in a horizontal plane, it would be well to consider the ratio of weight to horizontal or supporting surface in this kite.

The weight was 27,694 gms. (61 lbs.); the resolved horizontal or supporting surface was equivalent to 40.6250 square meters (437.3 sq. ft.), and the flying weight for comparison with other kites was 681.7 gms. per square meter of supporting surface (0.14 lbs. per sq. ft.).

The kite, in addition to its own weight, carried up a mass of dangling ropes and a rope-ladder, as well as two flying cords of manilla rope. The impedimenta of this kind weighed 28,148 gms. (62 lbs.). It also supported a man, Mr. Neil McDermid, who hung on to the main flying rope at such a distance from the cleat attached to the ground that when the rope straightened under the strain of the kite he was carried up into the air to a height of about 10 meters (over 30 ft.). The weight of this man was 74,910 gms. (about 165 lbs.). Thus, the total load carried by the kite, exclusive of its own weight, was 103,058 gms. (or 227 lbs.).

The whole kite, load and all, including the man, therefore, weighed 130,752 gms. (288 lbs.), and its flying weight was 1857.4 gms. per square meter of actual surface (0.38 lb. per sq. ft.); or 3218.5 gms. per square meter of supporting surface (0.66 lb. per sq. ft.).

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Appendix B. Partial Bibliography Relating to Aerial Locomotion, prepared, through the courtesy of the Smithsonian Institution, by Dr. Cyrus Adler, Assistant Secretary, in Charge of Library and Exchanges.

Dr. Adler says: “In accordance with your request, I am authorized to send you herewith a list of the writings of S. P. Langley, Octave Chanute, Otto Lilienthal, Lawrence Hargrave, and A. M. Herring, to be used in connection with your recent paper on aerial locomotion. I ought to explain that, excepting in the case of Mr. Langley's writings, I am not at all sure that the lists are complete, since the time afforded for bringing together the references was very short, and of course there may be publications in out-of-the-way journals which would only be revealed by a more extended inquiry. I have also appended a list of papers on the subject published by the Smithsonian Institution, as the Smithsonian publications are accessible in all libraries throughout the country, whereas many of the publications cited in the other lists are not readily to be found.”

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Proc. Wash. Acad. Sci., Vol. VIII. Plate IX.

Lilienthal Gliding Machine as reproduced in America for Chanute by Herring.

Gliding through the air on Chanute's Multiple-winged Glider.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XI.

The accident to Langley's Aërodrome.

From an instantaneous photograph loaned by the Smithsonian Institution. The machine caught in the launching ways and was injured, being precipitated into the water without having a chance to show what it could do in the air.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XII.

1. Starting a flight.

2. A high glide.

3. Soaring.

4. Landing.

The Wright Brother's Gliding Machine.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XIII.

A. Single-winged cell.

B. Four-celled kite.

C. Sixteen-celled kite.

D. Sixty-four-celled kite.

On this, the hollow plan of construction, an empty space appears in the middle of each kite, B, C, or D, equivalent in volume to one-half of the cubical contents of the whole structure. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XIV.

Carrying the Frost King on to the testing ground.

This kite was composed of 1,300 light-winged cells closely massed together. Photograph by E. H. Cunningham. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XV.

The Frost King in the air, flying in a ten-mile breeze, and supporting a man on the flying rope.

During the experiment the rope straightened under the pull of the kite, and the man was raised to a height of 30 or 40 feet. He was in great peril, but fortunately was brought down safely. Photograph by Alexander Graham Bell. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XVI.

Kite “Siamese Twins” seen from the front.

This kite was supported in the air by a strong wind exceeding, probably, as miles an hour. It was too heavy to be blown in a moderate breeze. Photograph by E. H. Cunningham. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XVII.

Kite “Siamese Twins,” seen from the rear, looking inside kite.

Composed of two distinct kites connected by a bridge, or truss, of strong cells, well beaded, for support of m?n. Photograph by F. H. Cunningham. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XVIII.

A Floating Kite, adapted to be towed out of the water.

Kite consists of a bridge, or truss, of tetrahedral cells with wings of Japanese waterproof paper upon two floats of light framework covered with oilcloth. A stout towing pole extends laterally across the lower part of the wing-piece at the front. Photograph by Douglas McCurdy. Illustration from the National Geographic Society.

Proc. Wash. Acad. Sci., Vol. VIII. Plate XIX.

The French Military Dirigible, “Patrie,” in flight.

The latest French airship. “La Patrie,” is 33¾ feet in diameter by 196 feet long, and has a capacity of 111,195 cubic feet. Driven by a 70-horsepower motor and two propellers, this dirigible has recently made about 30 miles an hour. Its lifting capacity is 2,777 pounds. Illustration from the *Scientific American.*

The New Deutsch Airship, “Ville de Paris,” the latest dirigible balloon.

The peculiar arrangement of twin, hydrogen-filled cylinders forms a sort of balancing tail. This airship has a length of 60 meters (196.85 feet) and a diameter of 10.8 meters (35.43 feet) while its capacity is 3,000 cubic meters (105,943 cubic feet). Its propellers are placed on either side of the body framework, or “nacelle,” and at about the center of the latter, which is boat-shaped. The weight which can be carried, outside of the equipment and the fuel sufficient for a ten hours' run, is about 1,100 pounds. A 70-horsepower Panhard motor is used. Illustration from the *Scientific American.*

Proc. Wash. Acad. Sci., Vol. VIII. Plate XX.

Count Von Zeppelin's Airship—the largest and fastest thus far constructed—coming out of its shed and performing various evolutions above Lake Constance.

[This airship, which is 38 feet in diameter by 410 feet in length and which has a capacity of 367.120 cubic feet, held itself stationary against a 33½-mile-an-hour wind in January last, by means of two 35-horsepower gasoline motors driving four propellers. The airship can lift three tons additional to its own weight, which gives it a radius of 3,000 miles at 31 miles an hour. On October 11, 1906, Count Zeppelin maneuvered this dirigible balloon above Lake Geneva, ascending to a height of 2,500 feet and steering the huge cigar-shaped aërostat very nicely. The airship is mounted on floats, so that it works equally well on the water. During one flight it remained in the air an hour and twenty minutes, although the steering-gear was caught in the skeleton framework and became partly unmanageable. The attempts proved also that the airship was dirigible in spite of its great size, as several complete circles were made while in the air. Illustrations from the *Scientific American.*